

**FLOW VISUALIZATION AND HOT GAS INGESTION CHARACTERISTICS  
OF A VECTORED THRUST STOVL CONCEPT**

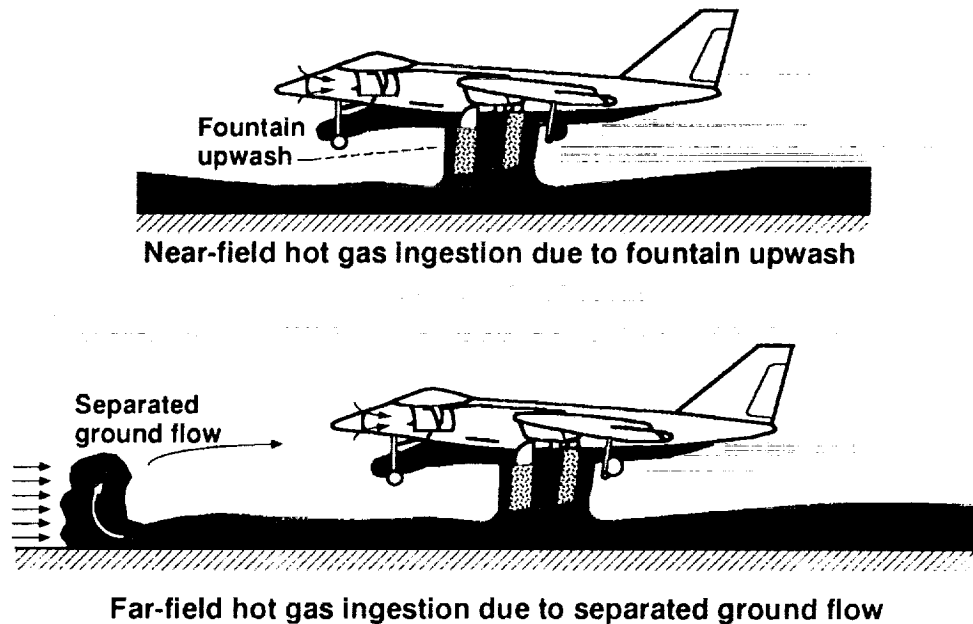
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Hot gas ingestion, the entrainment of heated engine exhaust into the inlet flow field, is the key development issue for advanced short takeoff and vertical landing aircraft (refs. 1 and 2).

A 9.2-percent scale short takeoff and vertical landing (STOVL) hot gas ingestion model was designed and built by McDonnell Douglas Corporation (MCAIR) and tested in the NASA Lewis Research Center 9- by 15-Foot Low Speed Wind Tunnel (LSWT). The test was conducted over a range of headwind velocities from 10 to 23 kn and nozzle exhaust temperatures from 500 to 1000 °F. The model was also tested over a range of model heights above the ground plane (0.20 to 12 in.) and a range of nozzle pressure ratios from 1.3 to 4.00. A copper vapor laser was used to create an illuminated flow field for flow visualization with the model in and out of ground effects. This paper will present results showing the flow field visualization which occurs when the model was in and out of ground effects. The effects of hot gas ingestion on the compressor face temperature rise and several other parameters will also be presented. The environmental effects of the hot gas on the ground and its effect on the acoustic loads as a function of the model height above the ground will also be presented.

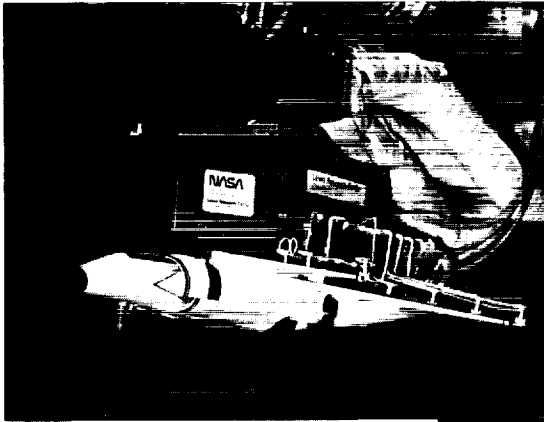
## Two Main Sources of Hot Gas Ingestion Near and Far Field



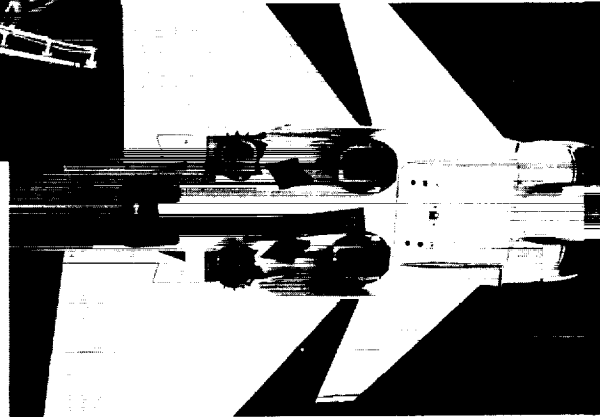
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Hot gas ingestion (HGI) can be categorized as near- and far-field phenomena. The near-field hot gas problem results from the hot exhaust jet impinging on the ground plane and the jet flowing in all directions. When this jet encounters another jet, it will set up a fountain which, if under the fuselage, will interact with the fuselage and flow forward into the inlet intake region. The near-field hot gas ingestion is generally the primary source of the hot gas ingestion. The near-field hot gas ingestion is a function of the model height above the ground plane (ref. 3). The far-field hot gas ingestion occurs when the ground jet flow separates from the ground ahead of the model and gets blown back into the inlet flow field. The far-field hot gas ingestion is a function of the headwind. The magnitude of the far-field hot gas ingestion is greatly reduced in comparison to that of the near field.

## Model 279-3C



Three-quarter view

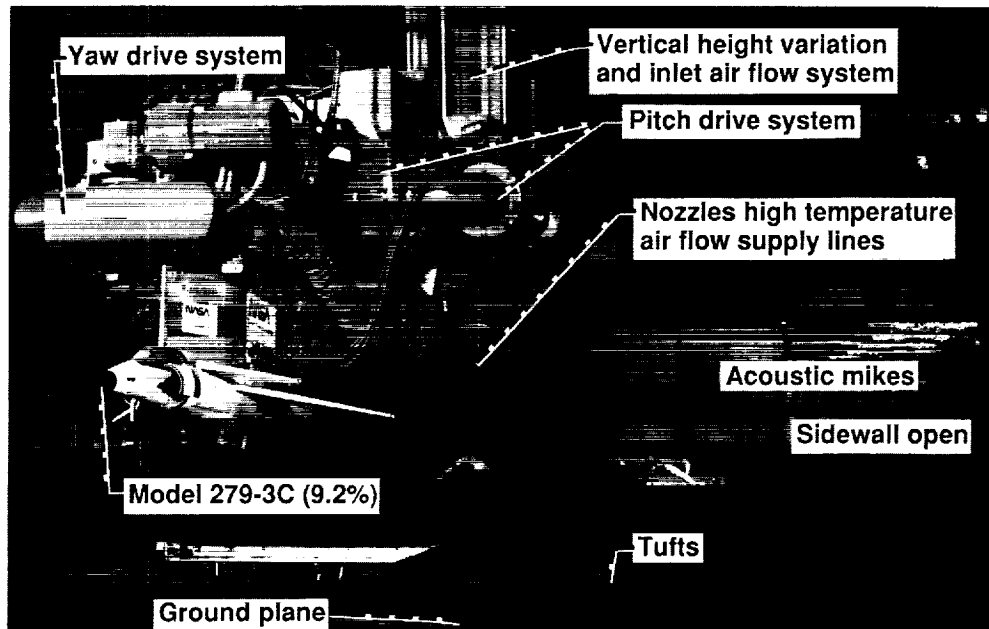


Undersurface view

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The undersurface of the hot gas ingestion (HGI) model, 279.3C, and a three-quarter view are shown. The HGI model consisted of five major subassemblies: the forward fuselage, center fuselage, aft fuselage, wings, and canards. The forward fuselage contained the main inlet and a translating cowl auxiliary inlet, which makes up the bifurcated inlet system. The inlet suction duct is part of the suction system which was used to create inlet (compressor face) flow. The center fuselage contained the nozzle system, and high pressure hot air lines supplied the hot air to the model's four nozzles. Lift improvement devices (LIDs) were also attached to the center fuselage. The LID's consist of longitudinal strakes, sidewalls, forward fence and aft fence (optional). The LID's generally enclosed the forward and aft pair nozzles.

## 9- by 15- Foot Low Speed Wind Tunnel Installation of Model 279-3C and "MISS"

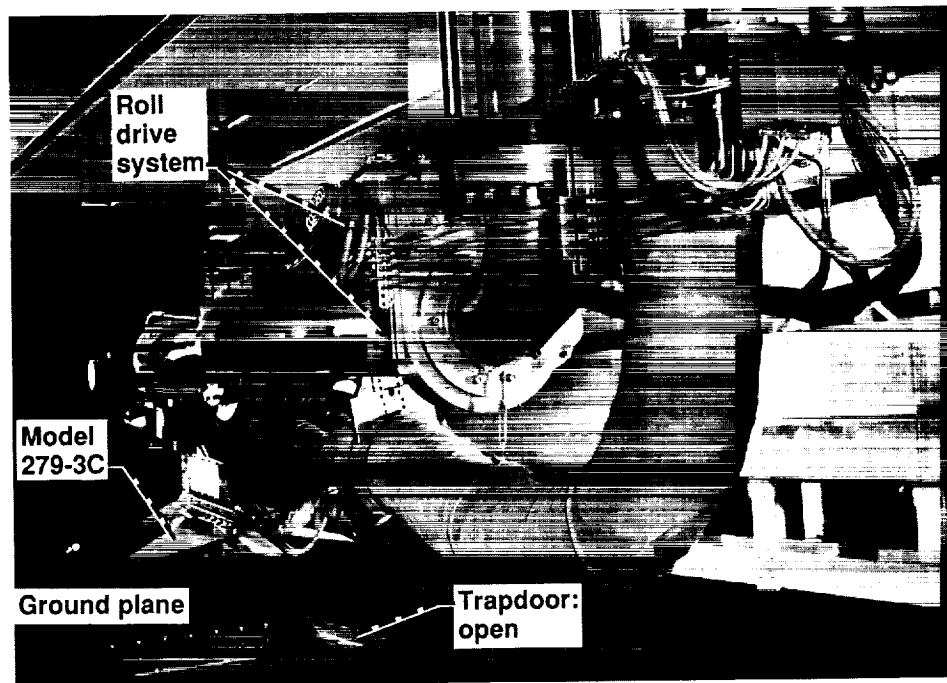


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The installation of a 9.2-percent scaled model and the supporting system in the 9- by 15-Foot Low Speed Wind Tunnel (LSWT) are shown in this figure. The NASA Lewis 9- by 15-foot LSWT was used to develop the hot gas ingestion data base. The 9- by 15-foot LSWT (constructed within the return leg of the 8- by 6-Foot Supersonic Wind Tunnel (SWT)), is 9 ft high, 15 ft wide, and has a 25-ft-long test section. The tunnel velocities for hot gas testing ranged from 8 to 23 kn.

The model supporting system includes a remotely controlled model integrated support system (MISS) that has four degrees of freedom (model height, yaw, pitch, and roll). The ground plane contained pressure, temperature measurements, and tufts for flow visualization. The sidewalls were open to vent lateral flow out of the test section, thus preventing flow circulation. Acoustic mikes and transducers (canard and wing) were used for noise and structural acoustic measurements, respectively.

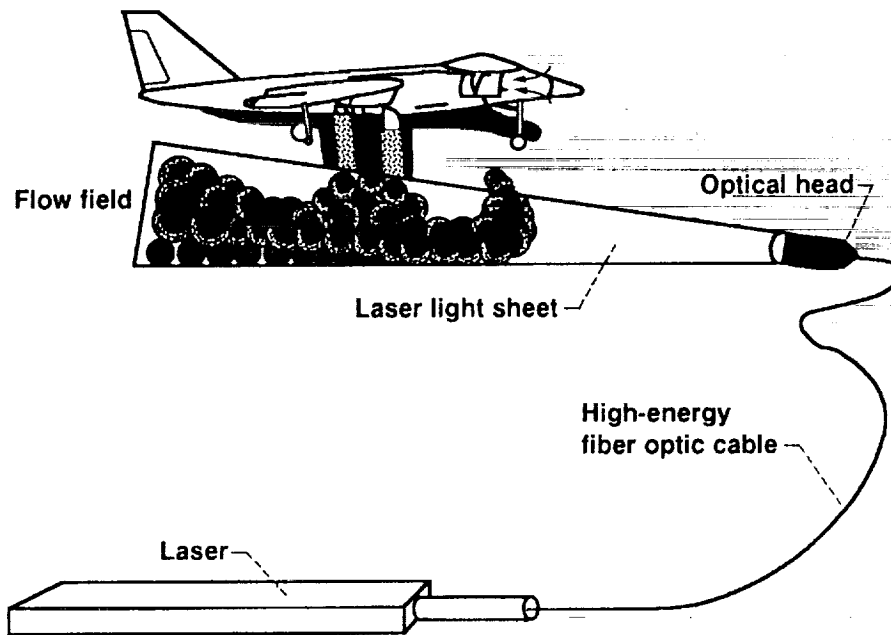
### Aft View of Model 279-3C With "MISS" Installed in 9- by 15- Foot LSWT



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The aft view shows the high-temperature air flow supply lines of the nozzles and the aft view of the MISS roll drive system. The pitch, roll, yaw, and height variation systems formed the inlet suction path. A sliding trap door (with a scavenging system) was located in the ground plane under the region of the model nozzles. The trap door was open when setting nozzle conditions to avoid artificially heating the model undersurface and ground environment. The model nozzle hot air flow was pulled through the trap door opening, down the duct located under the ground plane, and exhausted downstream of the test section by a pair of ejectors. When a data point was taken, the trap door was closed and the ejectors were automatically shut off.

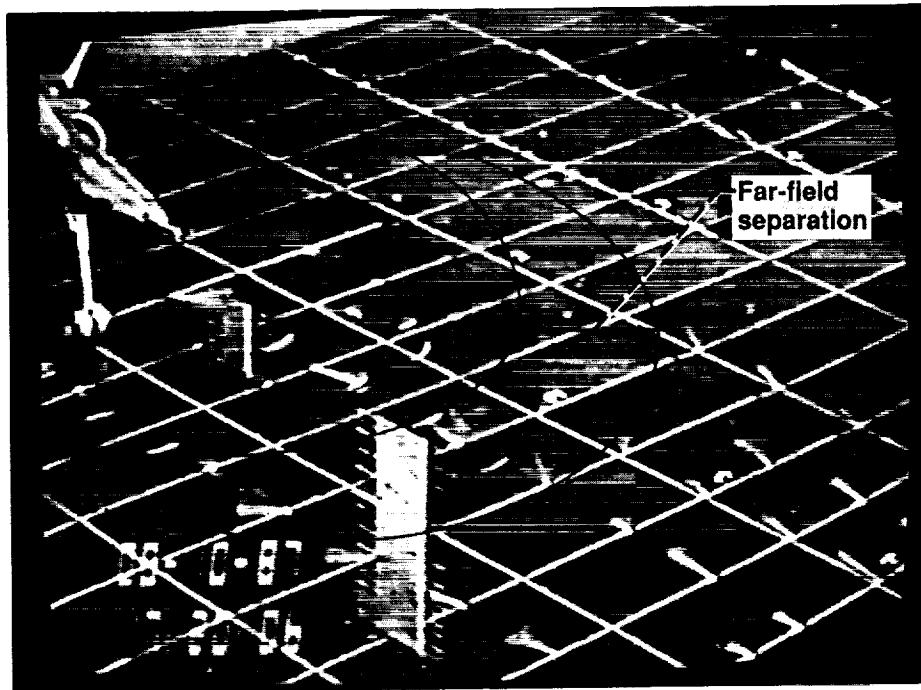
## Laser Sheet Illumination System



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A copper metal vapor laser was used to generate the illumination system for the flow field visualization. Atomized water was used as the seeding agent. The light from the laser was transmitted to the test section by means of a high-energy fiber optic cable. A traversing rig was used to position the optical head (sheet) at various stations in any of the three planes. The laser operates in the 510.6- and 578.2-nm wavelength. This was the first use of a laser sheet system in NASA Lewis Research Center propulsion wind tunnels.

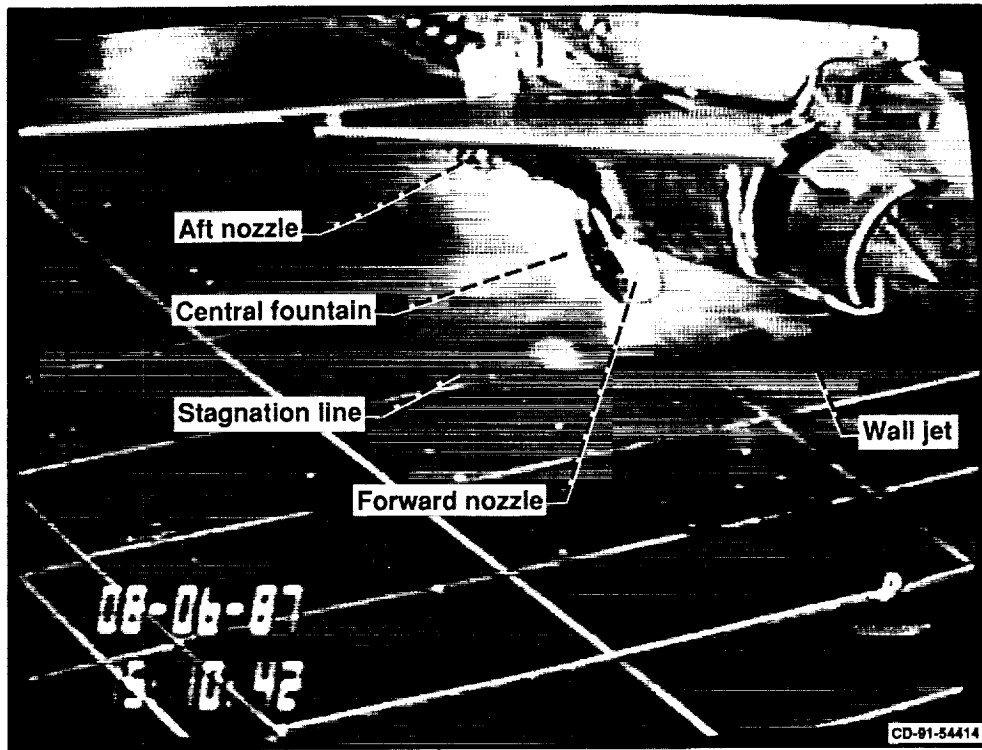
## Tufts Showing Far-Field Wall Jet Separation



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Tufts were used on the ground plane to determine the mid- and far-field ground flow characteristics. The tufts pointing toward the model are under the influence of the freestream headwind velocity. The tufts pointing away from the model are under the influence of the nozzle wall jet flow. At the region where they meet and the nozzle wall jet flow is slightly less than the headwind velocity, the wall jet separates and the tufts are unsteady (pointing away from and toward the model as a function of time). The region of nozzle wall jet influence is bounded in the lateral position by headwind velocity. The far-field separation can be observed where the tufts are unsteady.

## White Light and Water Mist Showing Near-Field Flow Characteristics

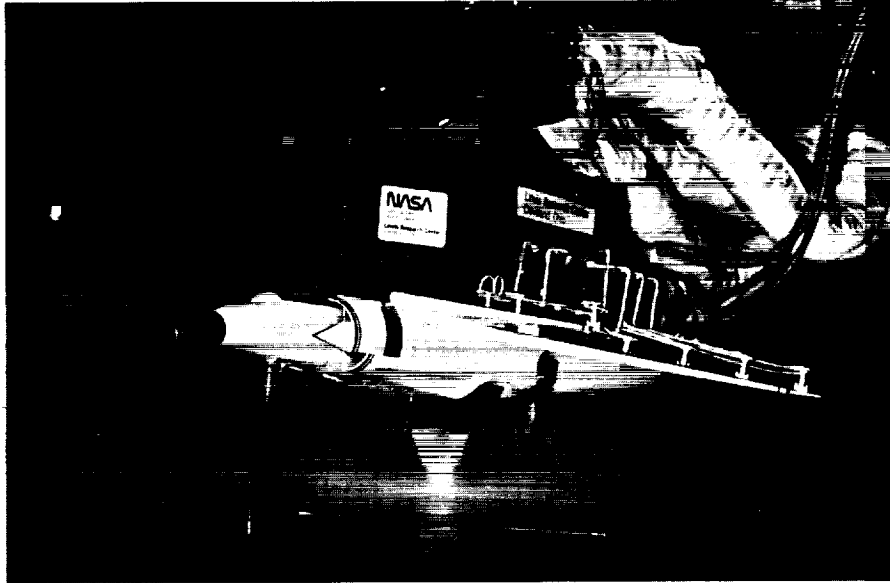


Flow visualization using white light and water at high pressure (atomized) produced a general (gross) view of the near-field flow characteristics as shown in this figure. The wall jet, stagnation line, and central fountain can be observed, although the details of the flow field are lost.



## Laser Sheet in Spanwise Direction

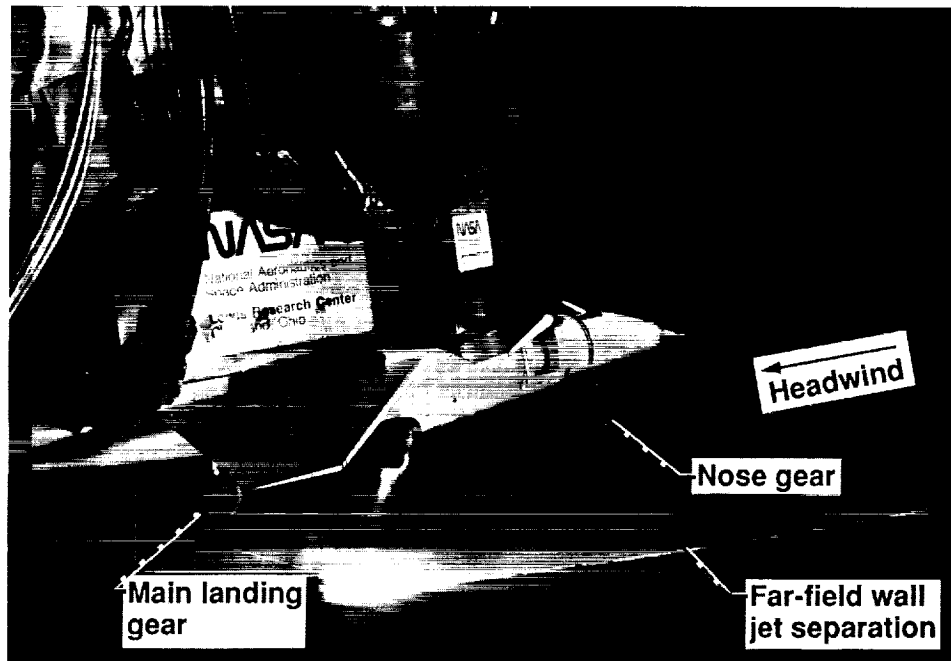
### Near-Field Flow Characteristics



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To obtain detailed information of the near- and far-field flows, it is necessary to use a laser sheet as the illumination source. In this figure, the laser sheet system is located in the spanwise direction. This position shows details of the near field and the laterally flowing wall jet. The laser sheet can be positioned over a range of axial stations to show the flow details, including the shocks in the nozzle jet plume.

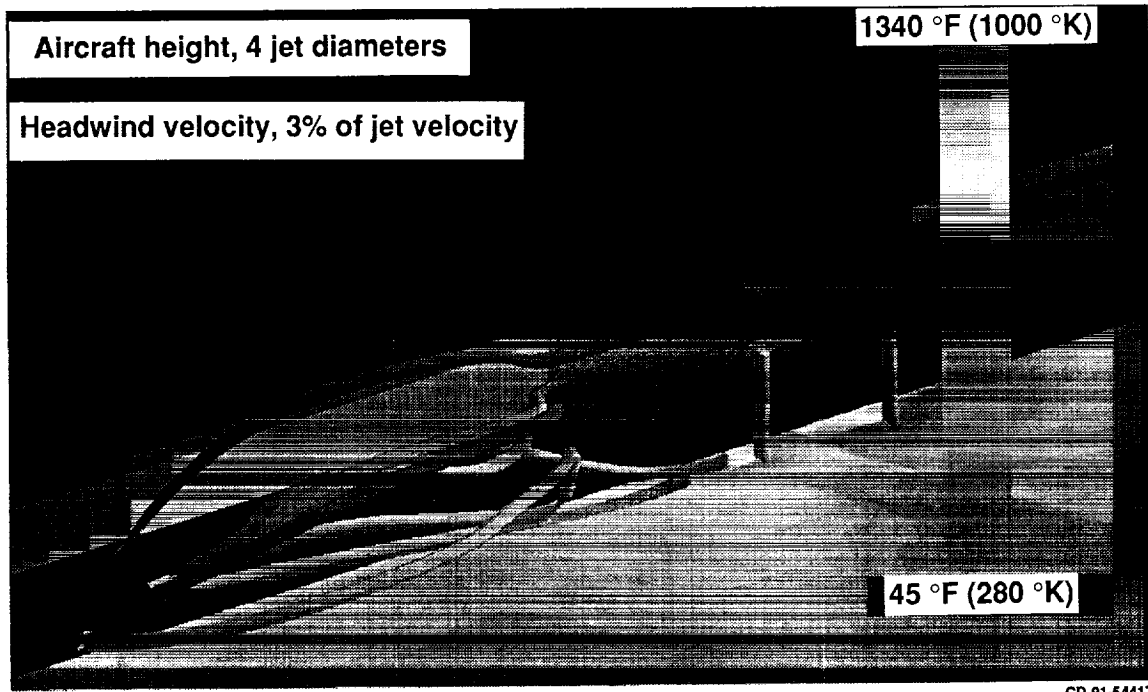
## Laser Sheet in Streamwise Direction Far- and Near-Field Flow Characteristics



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The laser sheet position in the streamwise direction will give a view in both the far and near fields. As a result, the effect of the height above the ground plane and the far-field interaction can be observed. The fountain between the forward and aft nozzles can also be seen.

## CFD Particle Traces Showing Ingestion



Using a state-of-the-art computer code, the flow field around a simple model of a short takeoff and vertical landing (STOVL) aircraft can be calculated. The computational fluid dynamics (CFD) code solves the turbulent, Reynolds-averaged, Navier-Stokes equations in three dimensions, using a multigrid technique. The CFD codes uses a  $k-\epsilon$  turbulence model. Shown is a particle tracing of the jet emanating from the nozzles.

## Image Enhancement



Video gray level output

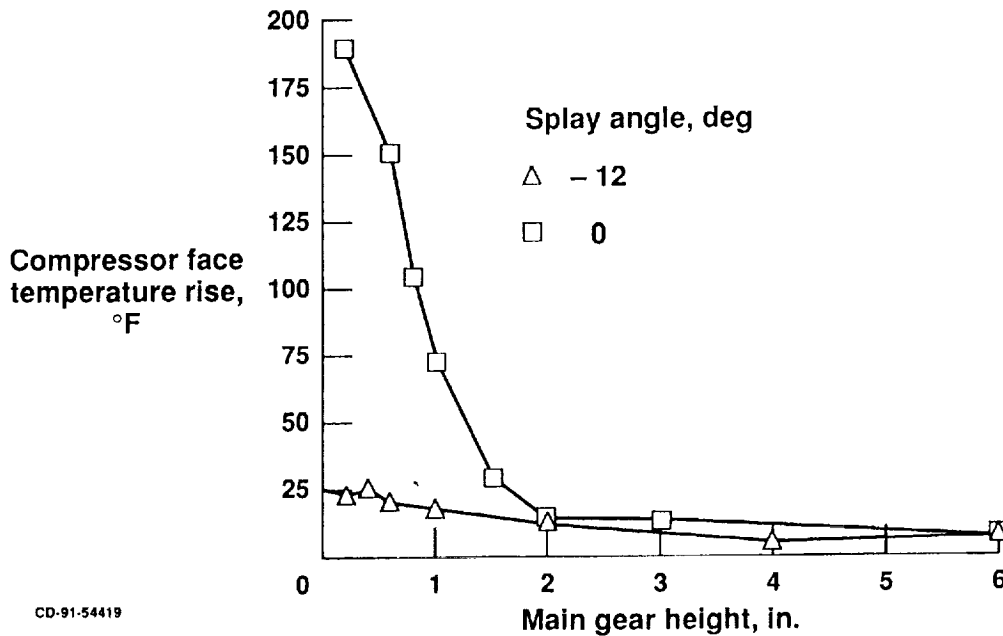


Color enhancement

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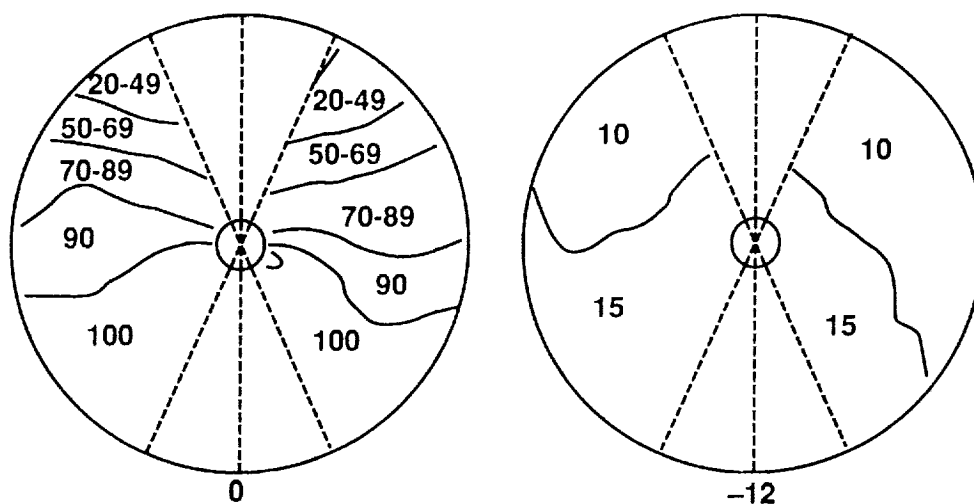
During the flow visualization test, a computer image enhancement program was used to color code the video gray level output. This allows the recording of the dynamic effect of the upwash fountain in the near field. Also, the density of the seeding material can be correlated with the hot region of the flow field. The dark region (in the color enhancement) located in the lighter region under the model represents the hottest (most dense) air flow region.

# **Effect of Forward Nozzle Splay Angle on HGI** (Nozzle design pressure ratio, 3.12; headwind velocity, 10 kn; nozzle jet temperature, 900 °F)



The effect of main landing gear height above the ground plane on the compressor face temperature rise is shown for splay configurations of -12 and 0°. The negative angle indicates that the nozzles were pointed inboard. The inboard splay is an attempt to create a single jet impinging on the ground, thereby reducing or eliminating the multijet impingement effect and, hence, the upwash fountain. The results show that inboard splay tends to reduce the hot gas ingestion at the compressor face.

# **Contour Maps of Compressor Face Temperature Rise** (Nozzle design pressure ratio, 3.12; headwind velocity 10 kn; main landing gear height, 0.10 in.)

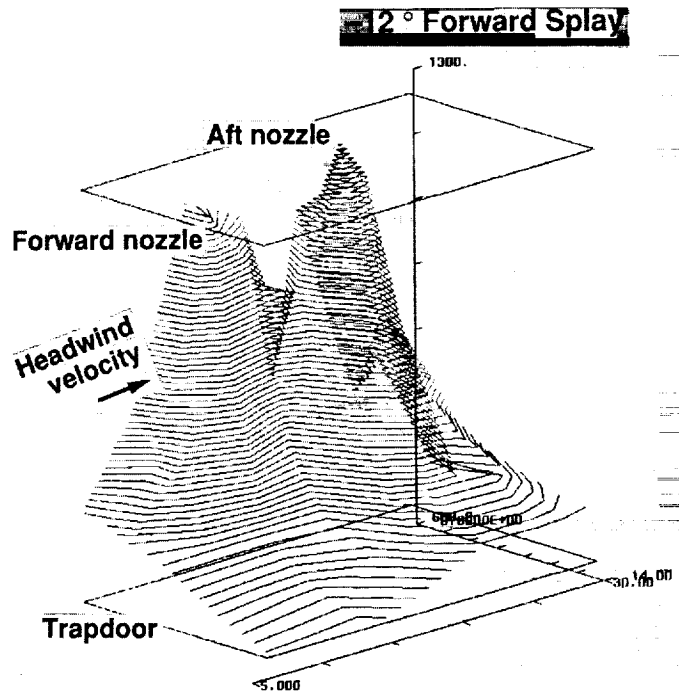
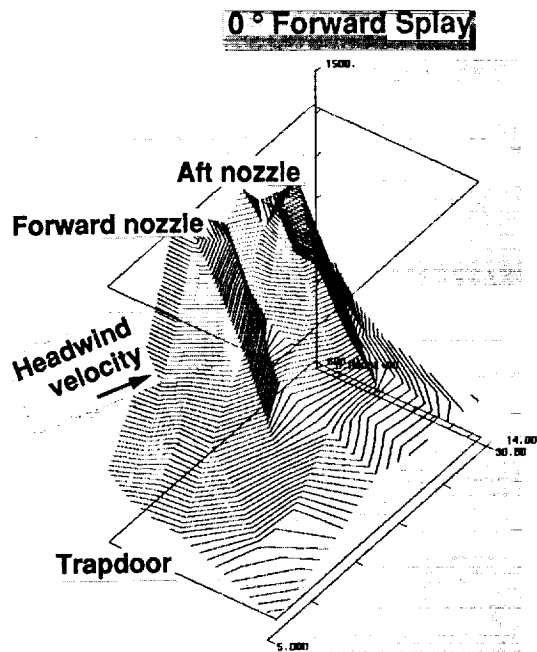


Forward nozzle splay configurations, deg

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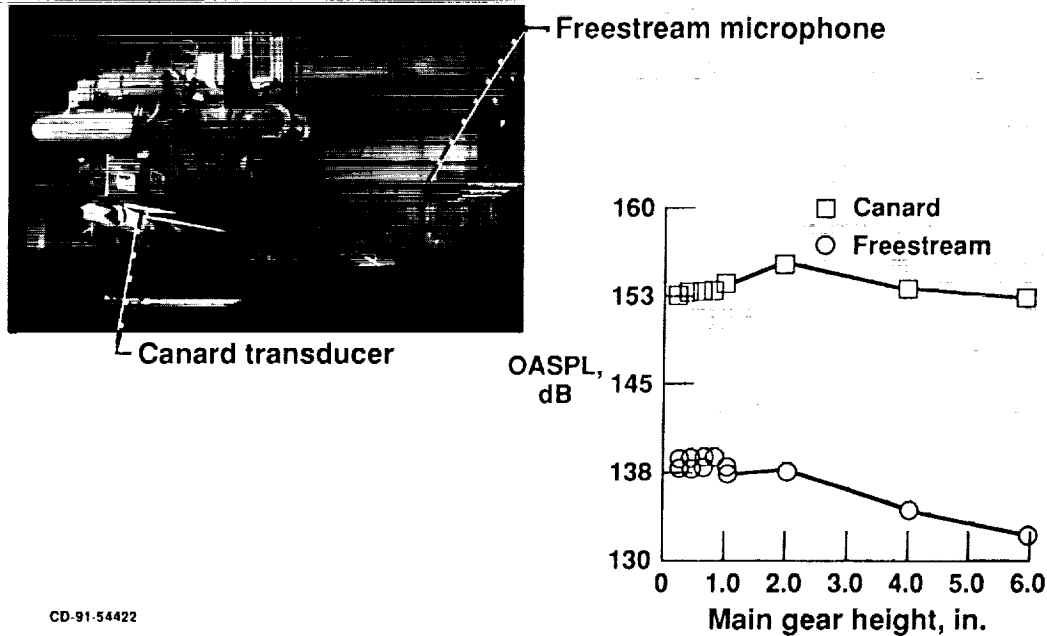
Contour maps of the compressor face temperature rise at the design landing condition for the -12 and 0° splay configurations are presented in this figure. In general, the hot gas was ingested in the lower inlet section, which results in a large compressor face temperature rise for the 0° splay configuration. Splaying the forward nozzles (-12°) to create a single jet impingement significantly reduced the compressor face temperature rise.

## Trapdoor Temperature Distributions



Shown here is the effect of forward nozzle splay angle on the ground plane temperature distribution. In general, the nozzles impose high-temperature footprints in the region of the nozzles. This temperature profile tends to decay rapidly as the flow moves upstream and laterally.

# **Model Height Effect on Acoustic Loads for 0 ° Forward Nozzle Splay** (Nozzle design pressure ratio, 3.12; headwind velocity, 10 kn; nozzle jet temperature, 500 °F)



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The effect of main landing gear height on the model acoustic and near-field environment is shown for the 0° forward nozzle splay configuration. The data are presented at the design landing nozzle pressure ratio of 3.12 for the aft nozzles and 3.03 for the forward nozzles; a nozzle exhaust temperature of 500 °F; and a headwind velocity of 10 kn. In general, the overall sound pressure level (OASPL) peaked when the model was approximately 2.00 in. (~20.00 in. full scale) above the ground plane. However, the near-field OASPL continued to increase until model touchdown.



## FUTURE PLAN

The next hot gas ingestion testing will use the following: a thermovision system that will provide detailed data of the thermofootprint on the ground plane and data of the model surface temperature distribution; a laser Doppler velocimeter (LDV) for detailed flow field measurements, which will improve CFD codes. Several advanced STOVL concepts will also be evaluated for hot gas ingestion, flow visualization, and noise characteristics.

## CONCLUDING REMARKS

Data bases for both flow visualization and hot gas ingestion (HGI) have been established for the thrust vectoring short takeoff and vertical landing (STOVL) concept of model 279-3C. The use of the high-energy fiber optic laser sheet illumination system provided significant insight into the near- and far-field flow characteristics with the model in and out of ground effects. Splaying the forward nozzles inboard resulted in a significant reduction in compressor face temperature rise. Both the local freestream environment and the structural acoustic noise increase with decreasing model height above the ground plane. The model integrated support system (MISS) and the many data acquisition systems established NASA Lewis as an excellent facility for testing STOVL HGI.

## REFERENCES

1. Johns, A.L.; Neiner, G.H.; Bencic, T.J.; Flood, J.D.; Amuedo, K.C.; Strock, T.W.; and Williams, B.R.: Hot Gas Ingestion Characteristics and Flow Visualization of a Vectored Thrust STOVL Concept. NASA TM-103212, 1990.
2. Johns, A.L.; Flood, J.D., Strock, T.W.; and Amuedo, K.C.: Hot Gas Ingestion Testing of an Advanced STOVL Concept in the NASA Lewis 9- by 15-Foot Low Speed Wind Tunnel With Flow Visualization. AIAA-88-3025, NASA RM-100952, 1988.
3. Amuedo, K.C.; Williams, B.R.; Flood, J.D.; and Johns, A.L.: STOVL Hot Gas Ingestion Control Technology. ASME 89-FT-323, June 1989.

